Rhizosphere 9 (2019) 110–111

Contents lists available at ScienceDirect

Rhizosphere

journal homepage: www.elsevier.com/locate/rhisph

Are dark septate endophytes bioindicators of climate in mountain ecosystems?

Anita Pandey

Center for Environmental Assessment and Climate Change, G.B. Pant National Institute of Himalayan Environment and Sustainable Development, Kosi-Katarmal, Almora 263 643, Uttarakhand, India

Dark septate endophytes (DSE), often referred as a miscellaneous group of ascomycetous anamorphic fungi, are making their way in root-microbiome research. Reports, on occurrence of these endophytic fungi, are increasingly emerging from various mountain ecosystems showing their dominance with increasing altitude; also causing shift in colonization of arbuscular mycorrhizal fungi (AMF). Can these DSE be seen as root associated bioindicators for climate change, by anticipating and monitoring shifts in the community structure of root mycorrhizae and endophytes?

Endophytic microorganisms colonize the internal tissues of the host plants, at least for a major period of their life cycle, without causing any disease symptoms. In this association, plants provide nutrition and shelter to the endophytes while the endophytes produce bioactive metabolites (such as, plant growth regulators, antimicrobials, insecticidals etc.) and contribute to the plant growth and its competeveness in a given ecosystem (Aly et al., 2010). Tolerance to biotic stress in host plants has been correlated to the production of natural products by fungal endophytes (Strobel et al., 2004). Detection of anti-cancer drug (taxol) in *Taxomyces andreanae*, isolated from *Taxus brevifolia*, is the premier example highlighting the importance of endophytes (Stierle et al., 1993). AMF are best known for forming the symbiotic association with roots of more than 80% terrestrial plants (Smith and Read, 2008).

In natural ecosystems, plants harbor a variety of endophytic microorganisms including archaea, bacteria and fungi; collectively referred as plant-microbiome (Quiza et al., 2015). Among these, the fungal endophytes are most abundant with their majority belonging to Ascomycota group Hypocreales. The plant-fungal symbiosis is likely to be decisive in predicting the ecosystem response to global change (Kivlin et al., 2013). Fungal endophytes have been classified in four functional groups on the basis of their host range, tissue(s) colonized, host colonization pattern, transmission mechanism between host generations, and ecological functions. Among these, Class 4 endophytes (DSE) are restricted to plant roots and distinguished by the presence of dark septate hyphae and microsclerotia (Rodriguez et al., 2009). The melanin content, found in DSE, provides protection to the hyphae against biotic or abiotic or both kind of stresses and play significant role in their survival, and the adaptation of the host plant under harsh climatic conditions (Kivlin et al., 2013; Jumpponen and Trappe, 1998; Robinson, 2001; Mandyam and Jumpponen, 2005). DSE have been reported to colonize the root tissues of the host species from tropics to arctic and alpine habitats. Ecological contributions of DSE are being reported from various stressful environments due to temperature, drought, and heavy metal stress. Utilization of their potential benefits in forest management and agricultural crops is also being understood (Newsham et al., 2009; Hilszczańska, 2016; Wang et al., 2016; Spagnoletti et al., 2017; Vergara et al., 2018).

High mountain ecosystems are sensitive to climate change due to the influence of low temperatures on ecological processes. Interesting findings on root colonization by DSE have been reported from the high altitude mountains where low mean annual temperatures prevail. These reports indicate the limitations of AMF in providing nutritional support to the host plants. Also, the fungal partners in high altitude and polar region plant species are mainly ectomycorrhizae and DSE (Newsham et al., 2009; Liu et al., 2017). Studies on the influence of DSE on plant growth under natural environments have been particularly emphasized (Newsham, 2011). The highest altitudinal records (high Andes of Peru´ and the Rockies of Colorado, USA) showed that the plant species are more colonized by DSE than AMF. The study also revealed significant decrease in AMF colonization with higher altitudes (Schmidt et al., 2008). Further, Huusko et al. (2016) explained that root colonization of DSE, that appears to be overlapping with mycorrhizal colonization, can give way to a shift in fungal community, from an AM-dominated to a DSE-dominated colonization. Colonization of DSE has also been reported from non-mycorrhizal plants (Liu et al., 2017). More recently, a comparative assessment between AMF and DSEs in roots of 62 plant species growing along the elevational gradient (3400–6150 m asl) in Himalaya highlighted the greater influence of extreme conditions on

E-mail address: anita@gbpihed.nic.in.

https://doi.org/10.1016/j.rhisph.2019.01.001
Received 11 December 2018; Received in revised form 25 January 2019; Accepted 26 January 2019
Available online 28 January 2019
2452-2198/ © 2019 Elsevier B.V. All rights reserved.

colonization of AMF as compared to the type of host plant species. Further, the AMF were totally absent above 5800 m whereas the DSE were recorded with even distribution throughout the elevational gradient (Kotilínek et al., 2017).

The Indian Himalayan region has received due attention on documentation of fungal diversity (Pandey et al., 2018); reports are also emerging on occurrence of DSE in high altitude plant species. Colonization of DSE in *Rhododendron campanulatum* and *R. anthopogon* roots, growing in high altitudes (2800–4500 m asl) was probably the first reports in this aspect (Chaurasia et al., 2005). The ongoing studies in the author's laboratory on other Himalayan species, both broad leaved and coniferous, highlight the occurrence of DSE related structures including dark septate hyphae and microsclerotia. Himalayan silver birch (*Betula utilis*) and Oak (*Quercus leucotrichophora*) roots are being observed with high colonization of DSE. Interesting observations have been reported from wheat that is cultivated in high mountain regions of Indian Himalaya. In field experiments conducted at three altitudes (1345 m in District Almora and 1900 and 2400 m asl in District Chamoli), maximum DSE colonization was observed at the highest altitude. It is noteworthy that at this altitude the crop remains covered with snow for 2–4 weeks during peak winters, indicating the role of DSE in providing nutrition as well as protection to the host in low temperature stress (Jain and Pandey, 2016).

Diverse cold ecosystems are likely to be dominated by the cold adapted microbial communities such as the DSE. The need to identify bioindicators for these ecosystems, affected by warming regional climates, is pressing. Lichens have already been considered as bioindicators in monitoring climate change (Stapper and John, 2015). Wide pH tolerance (extreme acidic to extreme alkaline) in extremophiles is indicative of ecological resilience possessed by these microorganisms with their ability to colonize the extreme environments (Dhakar and Pandey, 2016). Our increasing knowledge on structural and functional aspects of DSE that colonize the high altitude plants, certainly classifies these organisms as bioindicators of climate. The root mycorrhizal community composition shifts with elevation can probably be extended to other cold ecosystems, such as low and high altitude cold deserts, polar regions, and maybe others. The rate of shifts in rhizosphere communities with gradual warming is a front-line topic in plant-microbe associations under climate change scenarios. This will help understand the consequences of climate change at individual plant and crop species, as well as at the ecosystem level in cold regions.

References

Aly, A.H., Debbab, A., Kjer, J., Proksch, P., 2010. Fungal endophytes from higher plants: a prolific source of phytochemicals and other bioactive natural products. Fungal Divers. 41, 1–16.

Chaurasia, B., Pandey, A., Palni, L.M.S., 2005. Distribution, colonization and diversity of arbuscular mycorrhizal fungi in rhododendrons of central Himalayan region of India. For. Ecol. Manag. 207 (3), 315–324.

Dhakar, K., Pandey, A., 2016. Wide pH range tolerance in extremophiles: towards understanding an important phenomenon for future biotechnology. Appl. Microbiol. Biotechnol. 100, 2499–2510.

Hilszczańska, D., 2016. Endophytes – characteristics and possibilities of application in forest management. Leśne Prace Badawcze 77 (3), 276–282. ⟨www.lesne-prace-badawcze.pl⟩.

Huusko, K., Ruotsalainen, A.L., Markkola, A.M., 2016. A shift from arbuscular mycorrhizal to dark septate endophytic colonization in Deschampsia flexuosa roots occurs along primary successional gradient. Mycorrhiza 27, 129–138.

Jain, R., Pandey, A., 2016. Soil enzymes and microbial endophytes as indicators of climate variation along an altitudinal gradient with respect to wheat rhizosphere under mountain ecosystem. Rhizosphere 2, 75–84.

Jumpponen, A., Trappe, J.M., 1998. Dark septate endophytes: a review of facultative biotrophic root-colonizing fungi. New Phytol. 140, 295–310.

Kivlin, S.N., Emery, S.M., Rudgers, J.A., 2013. Fungal symbionts alter plant responses to global change. Am. J. Bot. 100 (7), 1445–1457.

Kotilínek, M., Hiiesalu, I., Košnar, J., Šmilauerová, M., Šmilauer, P., Altman, J., Dvorský, M., Kopecký, M., Doležal, J., 2017. Fungal root symbionts of high-altitude vascular plants in the Himalayas. Sci. Rep. 7, 6562. https://doi.org/10.1038/s41598-017-06938-x.

Liu, H., Li, T., Ding, Y., Yang, Y., Zhao, Z., 2017. Dark septate endophytes colonizing the roots of 'non-mycorrhizal' plants in a mine tailing pond and in a relatively undisturbed environment, Southwest China. J. Plant Interact. 12 (1), 264–271.

Mandyam, K., Jumpponen, A., 2005. Seeking the elusive function of the root-colonising dark septate endophytic fungi. Stud. Mycol. 53, 173–189.

Newsham, K.K., 2011. A meta-analysis of plant responses to dark septate root endophytes. New Phytol. 190, 783–793.

Newsham, K.K., Upson, R., Read, D.J., 2009. Mycorrhizas and dark septate root endophytes in polar regions. Fungal Ecol. 2, 10–20.

Pandey, A., Dhakar, K., Jain, R., Pandey, N., Gupta, V.K., Kooliyottil, R., Dhyani, A., Malviya, M.K., Adhikari, Priyanka, 2018. Cold adapted fungi from Indian Himalaya: Untapped source for bioprospecting. Proc. Natl. Acad. Sci. India (Section B): Biol. Sci. https://doi.org/10.1007/s40011-018-1002-0.

Quiza, L., St-Arnaud, M., Yergeau, E., 2015. Harnessing phytomicrobiome signaling for rhizosphere microbiome engineering. Front. Plant Sci. 6, 507.

Robinson, C.H., 2001. Cold adaptation in Arctic and Antarctic fungi. New Phytol. 151, 341–353.

Rodriguez, R.J., White Jr., J.F., Arnold, A.E., Redman, R.S., 2009. Fungal endophytes: diversity and functional roles. New Phytol. 182 (2), 314–330.

Schmidt, S.K., Sobieniak-Wiseman, L.C., Kageyama, S.A., Halloy, S.R.P., Schadt, C.W., 2008. Mycorrhizal and dark-septate fungi in plant roots above 4270 m elevation in the Andes and Rocky Mountains. Arct. Antarct. Alp. Res. 40 (3), 576–583.

Smith, S.E., Read, D.J., 2008. Mycorrhizal Symbiosis. Academic Press, London, UK.

Spagnoletti, F.N., Tobar, N.E., Pardo AFDi, V.M., Chiocchio, V.M., Lavado, R.S., 2017. Dark septate endophytes present different potential to solubilize calcium, iron and aluminum phosphates. Appl. Soil Ecol. 111, 25–32.

Stapper, N.J., John, V., 2015. Monitoring climate change with lichens as bioindicators. Pollut. Atmos. https://doi.org/10.4267/pollution-atmospherique.4936.

Stierle, A., Strobel, G.A., Stierle, D., 1993. Taxol and taxane production by Taxomyces andreanae, an endophytic fungus of Pacific yew. Science 260, 214–216.

Strobel, G.A., Daisy, B.H., Castillo, U., Harper, J., 2004. Natural products from endophytic microorganisms. J. Nat. Prod. 67, 257–268.

Vergara, C., Araujo, K.E.C., Alves, L.S., de Souza, S.R., Santos, L.A., Santa-Catarina, C., da Silva, K., Pereira, G.M.D., Xavier, G.R., Zilli, J.E., 2018. Contribution of dark septate fungi to the nutrient uptake and growth of rice plants. Braz. J. Microbiol. 49, 67–78.

Wang, J., Li, T., Liu, G., Smith, J.M., Zhao, Z., 2016. Unraveling the role of dark septate endophyte (DSE) colonizing maize (Zea mays) under cadmium stress: physiological, cytological and genic aspects. Sci. Rep. 6, 22028. https://doi.org/10.1038/srep22028.